

MAGNETIC ARRAY AND MAGNETIC SUSPENSION PLANAR MOTOR

TECHNICAL FIELD

The present invention relates to the fabrication of integrated circuits (ICs) and, more particularly, to a magnet array and a planar magnetic motor.

BACKGROUND

In the field of photolithographic tools, a motion device movable in multiple degrees of freedom is used to drive the movement of a motion stage. A magnetically levitated planar motion device can implement decoupled movements in six degrees of freedom and has a compact design by dispensing with intermediate gearings, which is conducive to higher motion efficiency of the device and can result in a higher positioning accuracy and a higher acceleration.

The aforementioned planar motion device is driven by a six-degrees-of-freedom (6DOF) planar magnetic motor which is either of a moving-coil type or of a moving-magnet type. Planar magnetic motors of the moving-magnet type have less cable restrictions on the mover and hence find more extensive use in motion stages of photolithographic tools. There is an existing planar magnetic motor of the moving-magnet type which uses a printed circuit board (PCB) as a stator, as shown in Fig. 1. The planar magnetic motor 1 includes a stator coil 11 and a magnet array 12. The stator coil 11 is divided into four sections, i.e., a first section 11A, a second section 11B, a third section 11C and a fourth section 11D. As illustrated in Fig. 2, the magnet array 12 includes a first magnet array 12A, a second magnet array 12B, a third magnet array 12C and a fourth magnet array 12D. In operation of the planar magnetic motor 1, energization of the first and second sections 11A, 11B induces the first magnet array 12A and second magnet array 12B to

produce forces in Z and X directions, respectively, and energization of the third and fourth sections 11C, 11D induces the third magnet array 12C and fourth magnet array 12D to produce forces in Z and Y directions, respectively. As the four magnet arrays, also known as force producers, can provide both vertical and horizontal thrusts, the mover of the planar magnetic motor as a whole can be driven to move in six degrees of freedom. Fig. 3 shows the magnetization directions of these magnet arrays each of which is a linear Halbach magnet array consisting of differently polarized magnets having a total length of $4r$ when put together.

The planar magnetic motors using linear Halbach magnet arrays suffer from a problem of low thrust outputs.

SUMMARY OF THE INVENTION

The present invention addresses the low thrust output problem of the prior-art planar magnetic motors by presenting a magnet array and a planar magnetic motor.

To this end, the magnet array according to the present invention is substantially square in shape and is constructed of at least one pair of linear Halbach magnet arrays and one pair of two-dimensional Halbach magnet arrays arranged in an X-Y plane, wherein the two-dimensional Halbach magnet arrays are disposed at two diagonal corners of the square.

Preferably, the two-dimensional Halbach magnet arrays each may include: N magnets; and S magnets and H magnets, both arranged around the N magnets, wherein the H magnets are magnetized toward the S magnets.

Preferably, the N magnets and S magnets in the two-dimensional Halbach magnet arrays may be square, wherein triangular N magnets and S magnets are further provided outermost in the two-dimensional Halbach magnet arrays.

Preferably, the N magnets and S magnets may be octagons, wherein N magnets

and S magnets, which are either in a shape of a half of an octagon or in a shape of a quarter of an octagon, are further provided outermost in the two-dimensional Halbach magnet arrays.

Preferably, the N magnets and S magnets may be densely arranged, with the H magnets in the two-dimensional Halbach magnet arrays filled in gaps left after the N magnets and S magnets have been arranged.

Preferably, the H magnets may be arranged between the N magnets and S magnets as well as in gaps left after the N magnets and S magnets have been arranged.

Preferably, the H magnets between the N magnets and S magnets may be magnetized toward the S magnets, and the H magnets in the gaps left after the N magnets and S magnets have been arranged may each be magnetized toward a corresponding one of the S magnets at an angle of 45 degrees with respect to both of the X and Y directions.

Preferably, the at least one pair of linear Halbach magnet arrays may include a pair of first magnet arrays and a pair of second magnet arrays, wherein magnets in the second magnet arrays are longer than magnets in the first magnet arrays.

Preferably, in the X-Y plane, magnets arranged at centers of the respective two-dimensional Halbach magnet arrays may have the same polarity as magnets arranged at centers of the respective first and second magnet arrays.

Preferably, each of the first and second magnet arrays may be constructed of N magnets, S magnets and H magnets between the N and S magnets, wherein the N magnets, S magnets and H magnets are arranged parallel to one another.

Preferably, the number of the linear Halbach magnet arrays may be the same as the number of the two-dimensional Halbach magnet arrays, wherein the linear Halbach magnet arrays and the two-dimensional Halbach magnet arrays are put

together to form a square.

The present invention also provides a magnetically levitated planar motor including the magnet array as defined above and a coil array disposed under the magnet array.

Preferably, the magnetically levitated planar motor may further include a back iron arranged on the magnet array.

Preferably, the coil array may include first coils for producing forces in the X direction and second coils for producing forces in the Y direction, wherein the first and second coils are stacked one above another and wired in crossed directions.

Preferably, the coil array may be a printed circuit board (PCB) coil array.

Preferably, insulators may be interposed between the first and second coils.

Preferably, the magnet array may act as a mover and the coil array as a stator, wherein the stator is wired with a phase-to-phase spacing of $4\tau/3$, wherein a pole pitch between adjacent N and S magnets in the linear Halbach magnet arrays in the magnet array is equal to a pole pitch between adjacent N and S magnets in the two-dimensional Halbach magnet arrays and is represented by τ .

Compared to the prior art, the present invention offers the following advantages: the magnet array according to the present invention is formed of both two-dimensional Halbach magnet arrays and linear Halbach magnet arrays, which allows for a higher thrust constant of the planar magnetic motor, when compared to an equally-sized magnet array simply formed of linear Halbach magnet arrays.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a top view of a planar magnetic motor of the prior art.

Fig. 2 shows a magnet array in the planar magnetic motor of the prior art.

Fig. 3 schematically illustrates the magnetization of the magnet array of the

prior art.

Fig. 4 is a top view of a planar magnetic motor constructed in accordance with a first embodiment of the present invention.

Fig. 5 schematically illustrates a magnet array in the planar magnetic motor according to the first embodiment of the present invention.

Figs. 6-8 respectively show configurations of a two-dimensional Halbach magnet array in the magnet array according to the first embodiment of the present invention (with square first magnet arrays).

Fig. 9 schematically illustrates a linear Halbach magnet array (first magnet array) in the magnet array according to the first embodiment of the present invention.

Fig. 10 schematically illustrates a linear Halbach magnet array (second magnet array) in the magnet array according to the first embodiment of the present invention.

Fig. 11 schematically illustrates the wiring of coils in the planar magnetic motor according to the first embodiment of the present invention.

Fig. 12 shows the operation of the planar magnetic motor according to the first embodiment of the present invention.

Fig. 13 shows how magnets in a Y-directional magnet array are put together in accordance with the first embodiment of the present invention.

Fig. 14 shows how magnets in an X-directional magnet array are put together in accordance with the first embodiment of the present invention.

Fig. 15 is a schematic illustration of a two-dimensional Halbach magnet array in the magnet array according to the first embodiment of the present invention (with rectangular first magnet arrays).

Fig. 16 is a schematic illustration of a magnet array constructed in accordance with a second embodiment of the present invention.

Fig. 17 shows how a planar magnetic motor constructed in accordance with the

second embodiment of the present invention operates.

Fig. 18 is a schematic showing magnet-array expansion in accordance with the second embodiment of the present invention.

Fig. 19 is a schematic illustration of a magnet array constructed in accordance with a third embodiment of the present invention.

Fig. 20 shows a linear Halbach magnet array in the magnet array according to the third embodiment of the present invention.

Fig. 21 shows the wiring of coils in the planar magnetic motor according to the third embodiment of the present invention.

In Figs. 1-3, 1 denotes the planar magnetic motor; 11, a stator; 11A, a first section; 11B, a second section; 11C, a third section; 11D, a fourth section; 12, the magnet array; 12A, a first magnet array; 12B, a second magnet array; 12C, a third magnet array; and 12D, a fourth magnet array.

In Figs. 4-15, 100 denotes the magnet array; 110, a two-dimensional Halbach magnet array; 111, an N magnet; 112, an S magnet; 113, an H magnet; 120, a first magnet array; 130, a second magnet array; 200, a stator; 210, a first coil; 220, a second coil; 230, an insulator; and 300, a back iron.

In Figs. 16-18, 100' denotes the magnet array; 110', a two-dimensional Halbach magnet array; 110A, a first two-dimensional Halbach magnet array; 110B, a second two-dimensional Halbach magnet array; 120', a linear Halbach magnet array; 120A, a first linear Halbach magnet array; and 120B, a second linear Halbach magnet array.

In Figs. 19-21, 100" denotes the magnet array; and 110", a linear Halbach magnet array.

DETAILED DESCRIPTION

The purposes, features and advantages of the invention will become more

apparent from the following detailed description of several specific embodiments which is to be read in connection with the accompanying drawings. It is noted that the drawings are provided in a very simplified form not necessarily presented to scale, with the only purpose for simplicity and clarity in explaining the embodiments.

EMBODIMENT 1

With reference to Fig. 4, a planar magnetic motor comprises a mover and a stator 200. The mover includes a magnet array 100 and a back iron 300 arranged on the magnet array 100. The stator 200 is formed of a printed circuit board (PCB) comprising first coils 210 for producing forces in an X direction and second coils 220 for producing forces in a Y direction. The first coils 210 and second coils 220 are orthogonal to each other and disposed one above another. Insulators 230 are provided between the first and second coils.

With focused reference to Fig. 5, the magnet array 100 comprises linear Halbach magnet arrays and two-dimensional Halbach magnet arrays 110. The number of the two-dimensional Halbach magnet arrays 110 is two. The linear Halbach magnet arrays include first magnet arrays 120 and second magnet arrays 130. Magnets in the second magnet arrays are longer than respectively identically polarized magnets in the first magnet array 120.

With focused reference to Figs. 6 to 8, in this embodiment, each two-dimensional Halbach magnet array 110 is formed by putting together magnets with three different magnetization directions. The magnets are: N magnets 111 that are magnetized outward from, and perpendicular to the plane of the figures; S magnets 112 that are magnetized inward from, and perpendicular to the plane of the figures; and H magnets 113 that are magnetized always horizontally toward the S magnets 112. The two-dimensional Halbach magnet array 110 has a pole pitch of τ both in the X and Y directions and is a square with a side length of 4τ .

In particular, the magnets in the two-dimensional Halbach magnet array 110 can be configured together in various ways as follows:

A first configuration is shown in Fig. 6, in which except for N magnets (or S magnets) located outermost in the two-dimensional Halbach magnet array 110 which are triangles, all other N magnets 111 and S magnets 112 are squares. H magnets 113 are provided between the N magnets 111 and S magnets 112. In other embodiments of the present invention, the outermost triangular magnets in the two-dimensional Halbach magnet array may be displaced with N magnets 111 and S magnets 112 which are each in a square shape and arranged in the two directions with H magnets 113 interposed between them.

A second configuration is shown in Fig. 7, in which except for N magnets (or S magnets) located outermost in the two-dimensional Halbach magnet array 110 which are each a half of an octagon (at edges of the two-dimensional Halbach magnet array 110) or a quarter of an octagon (at corners of the two-dimensional Halbach magnet array 110), all other N magnets 111 and S magnets 112 are octagons. In addition, the N magnets 111 and S magnets 112 are densely arranged, and H magnets 113 are filled in remaining gaps left after the N magnets 111 and S magnets 112 have been placed. Each of the H magnets 113 is magnetized toward a corresponding one of the S magnets 112 at an angle of 45 degrees with respect to a horizontal direction. In other embodiments of the present invention, the outermost magnets in the two-dimensional Halbach magnet array, which are each a half or a quarter of an octagon, may be displaced with N magnets 111 and S magnets 112 which are each in an octagonal shape and arranged in the two directions with H magnets 113 interposed between them.

A third configuration is shown in Fig. 8, in which N magnets 111 and S magnets 112 also have octagonal or partially octagonal shapes, and H magnets 113

are provided between the N magnets 111 and S magnets 112 as well as in remaining gaps left after the N magnets 111 and S magnets 112 have been placed. Each of the H magnets 113 in the gaps is magnetized toward a corresponding one of the S magnets 112 at an angle of 45 degrees with respect to a horizontal direction, and the other H magnets 113 are also each magnetized toward an S magnet 112.

With focused reference to Figs. 9 to 10, in the linear Halbach magnet arrays, each of the first and second magnet arrays 120, 130 is formed by putting together N magnets magnetized outwardly from the plane of the figures, S magnets magnetized inward from the plane of the figures, and H magnets magnetized toward the S magnets 112. Sides of the first and second magnet arrays 120, 130 that interface with the two-dimensional Halbach magnet array 110 each have a length of 4τ .

With focused reference to Fig. 5, the magnet array 100 is configured with the N magnets 111 and S magnets 112 arranged with a pole pitch of τ , the two two-dimensional Halbach magnet arrays 110 spaced from each other by a distance of Df both in the X and Y directions, the first magnet arrays 120 spaced from each other by a distance of Df in the X direction, and the two second magnet arrays 130 spaced from each other by a distance of Df in the Y direction. In this embodiment, each of the distances refers to a distance between center lines of the two magnet arrays, and Df satisfies the equation $Df=(N+0.5)\tau$, where N is an integer that is greater than or equal to 4.

In the planar magnetic motor, the coils in the stator 200 are wired with a phase-to-phase spacing of $4\tau/3$, as shown in Fig. 11.

With focused reference to Fig. 12, the planar magnetic motor operates in relation to energization of the coils as follows:

Upon energization of the first coils 210, the two-dimensional Halbach magnet arrays 110 and first magnet arrays 120 are induced to produce X-directional and

Z-directional forces.

When the second coils 220 are energized, the two-dimensional Halbach magnet arrays 110 and second magnet arrays 130 are induced to produce Y-directional and Z-directional forces. As there are provided two first coils 210 and two second coils 220, the mover is enabled to move in six degrees of freedom by controlling the energization of the individual coils.

Further, as shown in Fig. 13, in the Y direction, the two-dimensional Halbach magnet arrays 110 and first magnet arrays 120 are configured such that the magnet in each of the two-dimensional Halbach magnet arrays 110 that is arranged at a geometric center of the array in the X-Y plane has the same polarity as the magnet in each of first magnet arrays 120 that is arranged at a geometric center of the array in the X-Y plane, i.e., identically magnetized, and that the geometric centers in the X-Y plane are located in the same Y-Z plane. As each of the two-dimensional Halbach magnet array 110 and first magnet arrays 120 has a pole pitch of τ and a side length of 4τ , when the first coils 210 are energized, the two-dimensional Halbach magnet arrays 110 and first magnet arrays 120 produce equal forces in the X direction and/or the Z direction, as shown in Fig. 12.

Similarly, as shown in Fig. 14, in the X direction, the two-dimensional Halbach magnet arrays 110 and second magnet arrays 130 are configured such that the magnet in each of the two-dimensional Halbach magnet arrays 110 that is arranged at a geometric center of the array in the X-Y plane has the same polarity as the magnet in each of second magnet arrays 130 that is arranged at a geometric center of the array in the X-Y plane, i.e., identically magnetized, and that the two geometric centers in the X-Y plane are located in the same X-Z plane. As each of the two-dimensional Halbach magnet array 110 and second magnet arrays 130 has a pole pitch of τ and a side length of 4τ , when the second coils 220 are energized, the two-dimensional

Halbach magnet arrays 110 and second magnet arrays 130 produce equal forces in the Y direction and/or the Z direction, as shown in Fig. 12.

It is noted that the shape of the first magnet arrays 120 may either be square as shown in Fig. 5 or rectangular as shown in Fig. 15, and the length-wise and width-wise dimensions of the first and second magnet arrays 120, 130 are not limited in any way according to this embodiment.

EMBODIMENT 2

This embodiment differs from Embodiment 1 only in configuration of the magnet array.

In particular, as shown in Fig. 16, the magnet array 100' is constructed by putting together two two-dimensional Halbach magnet arrays 110' and two linear Halbach magnet arrays 120'. The two-dimensional Halbach magnet arrays 110' include a first two-dimensional Halbach magnet array 110A and a second two-dimensional Halbach magnet array 110B. The linear Halbach magnet arrays 120' include a first linear Halbach magnet array 120A and a second linear Halbach magnet array 120B.

The magnet array 100' operates in relation to energization of the coils in a manner explained in Fig. 17.

Energization of a first coil 210'B induces the first two-dimensional Halbach magnet array 110A and first linear Halbach magnet array 120A to produce X-directional and Z-directional forces, and energization of a second coil 220'B induces the second two-dimensional Halbach magnet array 110B to produce Y-directional and Z-directional forces, thereby maintaining movement of the mover in the Z, Rx, Ry and Rz directions.

Energization of another second coil 220'A induces the first two-dimensional Halbach magnet array 110A and second linear Halbach magnet array 120B to produce

Y-directional and Z-directional forces, and energization of another first coil 210'A induces the second two-dimensional Halbach magnet array 110B to produce X-directional and Z-directional forces, thereby maintaining movement of the mover in the Z, Rx, Ry and Rz directions.

The magnet array 100' according to this embodiment is constructed with magnets which are densely arranged to cover the whole area of the mover and thereby result in higher space utilization. In addition, multiple magnet arrays 100' can be used as modules to easily construct a larger-sized magnet array 100' of Fig. 18.

EMBODIMENT 3

This embodiment differs from Embodiments 1 and 2 in wiring of coils in the stator.

As shown in Fig. 19, a magnet array 100" according to this embodiment is constructed by four linear Halbach magnet arrays 110". Each of the magnet arrays 110", as shown in Fig. 20, is formed by putting together N magnets, S magnets and H magnets such that it has a pole pitch of τ and a total side length of 5τ . In the X and/or Y directions, the two parallel oriented linear Halbach magnet arrays 110" are offset by a distance of Df , which satisfies the equation $Df=(N+0.5)\tau$, where N is an integer that is greater than or equal to 5.

Accordingly, in the magnet array 100", the stator coils are wired with a phase-to-phase spacing of $5\tau/3$ so as to provide improved space utilization, as shown in Fig. 21.

It is apparent that those skilled in the art can make various modifications and variations to the present invention without departing from the spirit and scope thereof. Accordingly, it is intended that the invention embraces all such modifications and variations as fall within the scope of the appended claims and equivalents thereof.

CLAIMS

1. A magnet array, which is substantially square in shape and is constructed of at least one pair of linear Halbach magnet arrays and one pair of two-dimensional Halbach magnet arrays arranged in an X-Y plane, wherein the two-dimensional Halbach magnet arrays are disposed at two diagonal corners of the square.

2. The magnet array of claim 1, wherein the two-dimensional Halbach magnet arrays each comprise: N magnets; and S magnets and H magnets, both arranged around the N magnets.

3. The magnet array of claim 2, wherein the N magnets and S magnets in the two-dimensional Halbach magnet arrays are square in shape, and wherein the H magnets are magnetized toward the S magnets.

4. The magnet array of claim 3, wherein the two-dimensional Halbach magnet arrays further comprise triangular N magnets or S magnets disposed outermost in the two-dimensional Halbach magnet arrays.

5. The magnet array of claim 2, wherein the N magnets and S magnets in the two-dimensional Halbach magnet arrays are octagonal in shape.

6. The magnet array of claim 5, wherein the two-dimensional Halbach magnet arrays further comprise N magnets or S magnets which are either in a shape of a half of an octagon or in a shape of a quarter of an octagon and are disposed outermost in the two-dimensional Halbach magnet arrays.

7. The magnet array of claim 5, wherein the N magnets and S magnets are densely arranged, and wherein the H magnets are filled in gaps left after the N magnets and S magnets have been arranged.

8. The magnet array of claim 5, wherein the H magnets are arranged between the N magnets and S magnets as well as in gaps left after the N magnets and S magnets have been arranged.

9. The magnet array of claim 7 or 8, wherein the H magnets between the N magnets and S magnets are magnetized toward the S magnets, and wherein the H magnets in the gaps left after the N magnets and S magnets have been arranged are each magnetized toward a corresponding one of the S magnets at an angle of 45 degrees with respect to both of the X and Y directions.

10. The magnet array of claim 1, wherein the at least one pair of linear Halbach magnet arrays comprises a pair of first magnet arrays and a pair of second magnet arrays, and wherein magnets in the second magnet arrays are longer than magnets in the first magnet arrays.

11. The magnet array of claim 10, wherein in the X-Y plane, magnets arranged at centers of the respective two-dimensional Halbach magnet arrays have a same polarity as magnets arranged at centers of the respective first and second magnet arrays.

12. The magnet array of claim 10, wherein each of the first and second magnet arrays is constructed of N magnets, S magnets and H magnets between the N and S magnets, and wherein the N magnets, S magnets and H magnets are arranged parallel to one another.

13. The magnet array of claim 1, wherein a number of the linear Halbach magnet arrays is same as a number of the two-dimensional Halbach magnet arrays, and wherein the linear Halbach magnet arrays and the two-dimensional Halbach magnet arrays are put together to form a square.

14. A magnet array, which is a square magnet array formed by arranging a plurality of magnet arrays as defined in claim 1 along the X and Y directions.

15. A magnetically levitated planar motor, comprising: the magnet array as defined in claim 1 or 14; and a coil array disposed under the magnet array.

16. The magnetically levitated planar motor of claim 15, further comprising

a back iron arranged on the magnet array.

17. The magnetically levitated planar motor of claim 15, wherein the coil array comprises first coils for producing forces in the X direction and second coils for producing forces in the Y direction, and wherein the first and second coils are stacked one above another and wired in crossed directions.

18. The magnetically levitated planar motor of claim 15, wherein the coil array is a printed circuit board (PCB) coil array.

19. The magnetically levitated planar motor of claim 17, wherein insulators are inter-posed between the first and second coils.

20. The magnetically levitated planar motor of claim 15, wherein the magnet array acts as a mover and the coil array acts as a stator, and wherein the stator is wired with a phase-to-phase spacing of $4\pi/3$, wherein a pole pitch between adjacent N and S magnets in the linear Halbach magnet arrays in the magnet array is equal to a pole pitch between adjacent N and S magnets in the two-dimensional Halbach magnet arrays and is represented by τ .